International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD)
ISSN(P): 2249-6866; ISSN(E): 2249-7978
Vol. 7, Issue 3, Jun 2017, 55-70

TRANS STELLAR • Journal Publications • Research Consultancy

Original Article

CFRP SHEAR STRENGTHENING PERFORMANCE OF VARYING HOLLOWNESS RATIO REINFORCED SELF COMPACTING CONCRETE BOX T-BEAMS

ALI HAMEED AZIZ ALSARAJ[1] & MUHAMMAD ALI JASEM[2]

[1]*Assistant Professor Dr., Civil Engineering Department, AlMustansiriyah Engineering College / Almustansiriyah University / Baghdad, Iraq*

[2]*M.Sc. Student, Civil Engineering Department, AlMustansiriyah Engineering College / Almustansiriyah University / Baghdad, Iraq*

ABSTRACT

There is a few interesting research about reinforced concrete box beams under the effect of shear loads; therefore, a shear failure mechanism is not understood well. In the present paper, the effect of hollowness ratio variation and strengthening by CFRP strips on the structural performance of reinforced self-compacting concrete (SCC) box beams, subjected to shear loads is studied. Eighteen reinforced SCC beam specimens have a dimension of (1500x200x300mm) for length; width and height, respectively were poured and tested. The tested beams were divided into three groups based on the top flange dimensions. For each group, three variables were adopted; section, type (box or solid), hollowness ratio and strengthening by CFRP strips. Experimental results show that the increasing of the webs thickness from (50mm) to (62.5mm, 75mm and cast without hollow) ultimately result in capacity increase of about (11%, 18% and 40%), (6%, 9% and 17%) and (10%, 18% and 37%) for rectangular, T-beams with (300 mm) top flange and T-beams with (400 mm) top flange, respectively. Increasing in top flange width from (200mm) to (300mm) led to an increase in ultimate capacity about (30%, 24%, 20% and 10%) in comparison to its counterpart beams respectively. Increasing of top flange width from 300mm to 400mm led to an increase in the ultimate capacity about (18%, 25%, 27% and 18%) in comparison to its counterpart beams, respectively.

KEYWORDS: Shear, Self-Compacting Concrete, T-section, Box Beams, Strengthening & CFRP Strips

Received: May 09, 2017; **Accepted:** May 25, 2017; **Published:** Jun 03, 2017; **Paper Id.:** IJCSEIERDJUN20177

INTRODUCTION

Box beams are referred to as thin-walled structures, because of their cross-sectional dimensions. Box beams have been used extensively in bridge construction, because of the structural advantages of closed box section. The closed box section has a high tensile stiffness, which ensures good transverse distribution of eccentric loads. As the box section has a high bending stiffness, this leads to efficient use of the complete cross-section. However, prediction of the response of box beam bridges involves many difficulties caused by the complex interaction of the individual structural effects (1). A box girder structure consists of top and bottom flanges connected by vertical or inclined webs to form a cellular section. It is one of the most popular forms of highway bridges; primarily because of the high flexural and torsion rigidities. The use of box beams in highway-bridge construction has proven to be a very efficient structural solution (2).

The shear failure has different characters, as compared to bending, in which the former is more brittle and often occurs without any forewarning. One of the techniques used for the strengthening of the existing reinforced

concrete members involves externally bonding CFRP composite materials, by means of epoxy adhesives. This technique, improves the structural performance of a member under ultimate load and service load [3, 4].

Several researchers are interested in box beams under the effect of flexural, shear and torsion loads [5]. The shear behaviour of reinforced self-compacting concrete deep box beams strengthened internally with transverse ribs, also studied [6]. Furthermore, the effect of transverse internal ribs on shear strength evaluation of hollow RC beams was studied [7].

Strengthening of continuous SCC hollow beams under shear stresses using warped CFRP strips was studied experimentally [8].

RESEARCH SIGNIFICANT

Despite the many investigations of the shear behaviour of RC beams with solid or box cross section, little has been done on the applications of SCC with a complete absence for the effect of hollowness ratio variation of box beams on structural performance. So, the need to study the shear behaviour of such sections with strengthening by CFRP technique gives more attention.

In the present study, shear behaviour of reinforced self-compacting concrete hollow T-Beams, which contain different flange dimensions and different hollowness ratios will be examined, as well as the effect of strengthening of specimens using carbon fiber reinforced polymers (CFRP).

EXPERMINTAL STUDY

Experimental Program

The experimental program consists of pouring and testing of eighteen SCC rectangular and T-beams specimens. The specimens have a dimension of (1500x200x300mm) for length; width and height respectively. The top flange width was varied (between 200mm to 400mm). The beam specimens were divided into three main groups based on the width of the top flange, and each main group has subdivisions according to the thinned wall web thickness and the strengthening using CFRP. All beam specimens were simply supported of (1500mm) long and tested over an effective span of (1400mm). The tested beams were designed in accordance with ACI 318-M08 Code [9], with minimum shear reinforcement (to ensure that the beams will fail in shear), under the effect of monotonically concentrated load at mid span. The beam length, shear span- effective depth ratio (a/d), strength of concrete, longitudinal and transverse reinforcement were kept constant for all tested beams.

Table 1 shows beam designations and the division of samples. It may be noted that, the tested beams were denominated by two symbols, beam number (B#) and group number (G#). The longitudinal and cross-section details of the test specimens are shown in Figures 1 to 6.

Table 1: Details of slabs variables

Group	Beam Designation	Beam Type	Dimensions (mm)				HR (%)	Strengthening
			Top Flange		Web	H		
			b_f	t_f	t_w			
Group-1	B1G1*	Rectangular	200	50	2x50	300	31.6	None
	B2G1				2x62.5		23.75	None
	B3G1				2x62.5		23.75	CFRP
	B4G1				2x75		15.8	None
	B5G1		-	-	200 (Solid)		0	None
Group	B1G2*	T-Beam	300	50	2x50	300	29.1	None

	B2G2				2x62.5		21.9	None
	B3G2				2x62.5		21.9	CFRP
	B4G2				2x75		14.5	None
	B5G2		-	-	200 (Solid)		0	None
Group-3	B1G3*	T-Beam	400	50	2x50	300	27	None
	B2G3				2x50		27	CFRP
	B3G3				2x62.5		20.3	None
	B4G3				2x62.5		20.3	CFRP
	B5G3				2x75		13.53	None
	B6G3				2x75		13.53	CFRP
	B7G3		-	-	200 (Solid)		0	None
	B8G3				200 (Solid)		0	CFRP

*Group Reference Beam b_f=Flange Width t_f= Flange Thickness t_w= Web Thickness H=Beam Depth HR=Hollowness Ratio

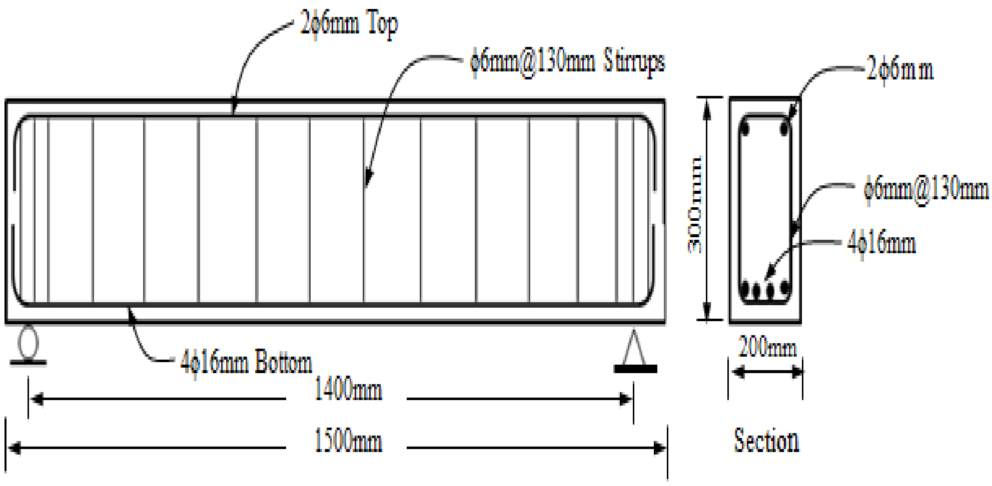

Figure 1: Solid Rectangular Beam Specimen Details

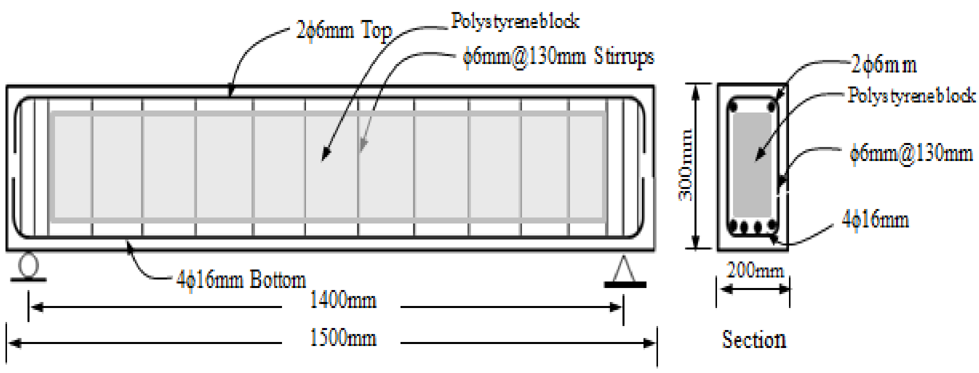

Figure 2: Box Rectangular Beam Specimen Details

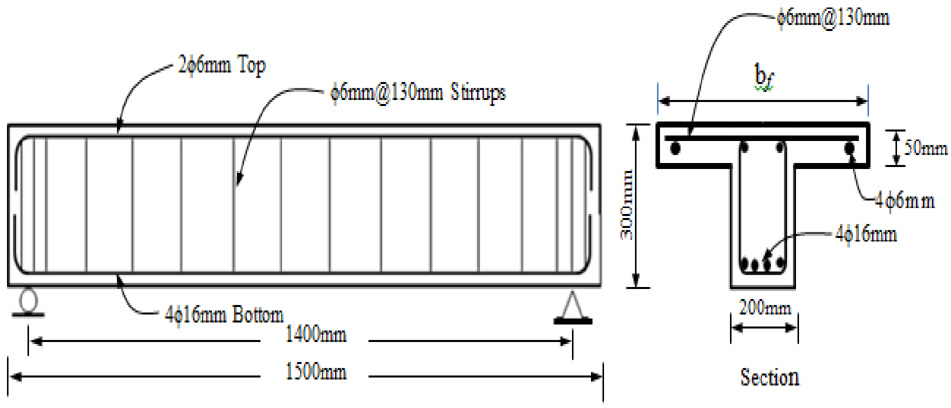

Figure 3: Solid T-Shaped Beam Specimen Details

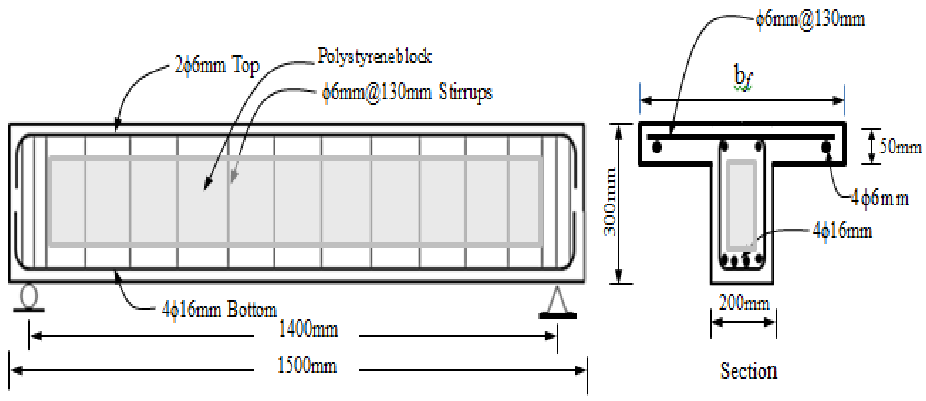

Figure 4: Box T-Shaped Beam Specimen Details

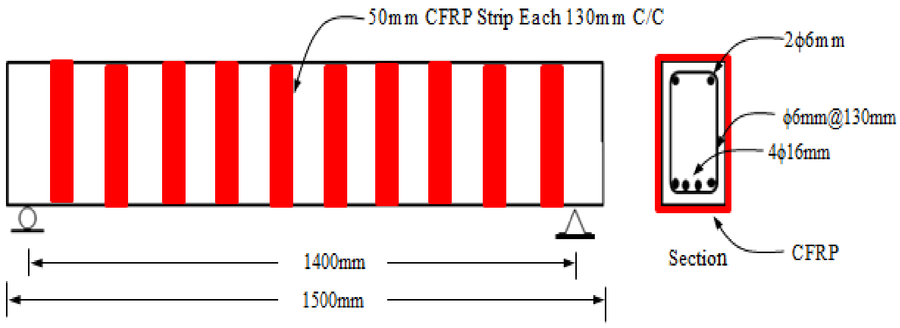

Figure 5: Strengthening of Rectangular Beams by CFRP

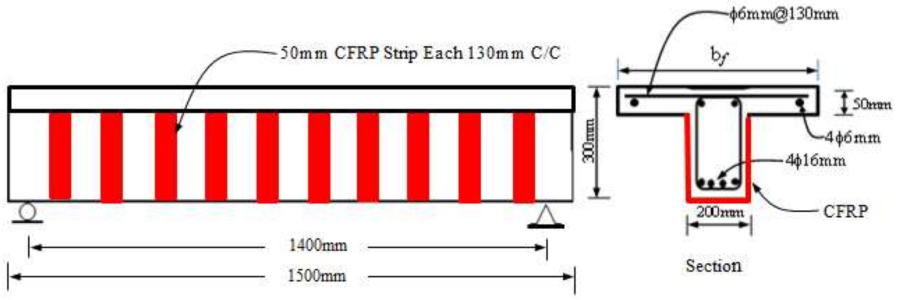

Figure 6: Strengthening of T-Shaped Beams by CFRP

MATERIALS

In manufacturing the beam specimens, properties and description of the used materials as well as properties of steel bars are presented in Tables 2 and 3, respectively. Concrete mix proportions are presented in Table 4.

Table 2: Properties of Construction Materials

Material	Descriptions
Cement	Ordinary Portland Cement (Type I)
Sand	Natural sand from Al-Ukhaidher region with maximum size of (4.75mm)
Gravel	Crushed gravel of maximum size (12mm)
Limestone powder	Fine limestone powder (locally named as Al-Gubra) of Jordanian origin
Superplasticizer	Glenium 51 manufactured by BASF Construction Chemicals, Jordan
Water	Clean tap water

Table 3: Properties of Steel Bars

$D_{nominal}$ (mm)	$D_{measured}$ (mm)	Bar Type	f_y (MPa)	f_u (MPa)	E_s^{**} (GPa)	Elongation %
6	6	Deformed	473	651	200	16
16	15.9	Deformed	491	653	200	16

*Each value is an average of three specimens (each 50 cm. length) **ACI 318-M08

Table 4: Mix Proportions Details

Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Limestone (kg/m^3)	Water ($liter/m^3$)	Superplasticizer ($Liter/m^3$)
400	797	767	170	190	7.5

Properties of Hardened Concrete

The compressive strength test has been carried out in accordance with ASTM C39/C39M-01[10] and BS 1881-116 1983 [11]. Nine (15cm) cubes and nine (15x30cm) cylindrical specimens have been used to estimate compressive strength of concrete for three mixes. The compressive strength of concrete had been computed at three different ages (7, 14 and 28 days). The indirect tensile strength was carried out, according with ASTM C496-96 [12]. (15x30cm) cylindrical specimens have been used to compute splitting tensile strength of concrete. The specimens were tested at the age of 28 days. Static modulus of elasticity (Ec) was carried out according to ASTM C469-02 [13]. (15x30cm) cylindrical specimens were used to compute modulus of elasticity of concrete. All results are shown in Table 5.

Table 5: Mechanical Properties of Hardened SCC

SCC	f_c'(MPa)	f_{cu}(MPa)	f_{ct}(MPa)	E_c(MPa)
	28.7	34.5	2.95	24750

Reinforcement Design

All beams were designed in accordance with ACI 318-M08 Code [9]. The reinforcement design is divided into two types: Longitudinal and transverse. Properties of steel bars are reported and presented in Table 3.

Longitudinal Reinforcement

The main longitudinal reinforcement was designed to ensure that the flange was in compression and the section would fail in shear. The main reinforcement consisted of (4ϕ16mm) mild, hot rolled steel bars worked as tension

reinforcement. Longitudinal tension reinforcement had 90-degree hooks at the beam ends, with (160mm) long to ensure appropriate anchorage. Also, (2ϕ6mm) in rectangular sections and (4ϕ6mm) in T-sections deformed steel bars were used as holding bars at the top to hold the transverse reinforcement in position, when concrete was being pouring and to prevent concrete fragments in flange

Transverse Reinforcement

To ensure that the beam will fail in shear, the beams were reinforced with minimum shear reinforcement. (ϕ6mm) at (130mm) c/c deformed bars were used as stirrups. The stirrups were detailed in form to work as web reinforcement (stirrups) and transverse reinforcement at the flange overhang, there is additional transverse reinforcement at flange, (ϕ6mm) at (130mm) c/c deformed bars arranged between the spacing of stirrups. Both longitudinal and vertical bars were settled and connected together through using of (1mm) steel wires to form the reinforcement mesh. The reinforcement mesh has been placed inside the mold with (18mm) concrete cover for tensile reinforcement and (10mm) from top. Details of beam reinforcements are shown in Figure 7.

Figure 7: Rectangular and T-Beam Reinforcement Details

Moulds

Wooden moulds with (18mm) thickness plywood were used to cast beam specimens. Each mould consists of a bed and two movable sides, these sides have been fixed together by screws to form the required shape. Polystyrene blocks are used to form the hollows inside the beams; because of lightweight and its facility to configure with the required dimensions. For all tested beams, beyond the cells (at the ends), whole beam section was solid concrete.

Test Measurement and Instrumentation

All beams as well as control specimens were tested by using the Hydraulic Machine (MFL system) with a maximum range capacity of (3000kN). Vertical deflection was measured at two points, at the mid-span and at one-third of span of beam specimens by using dial gauges of (0.01mm/div.) accuracy at every load stage. The gages were placed under the bottom face of the tested beams. The strains were measured by means of strain gauges attached in different locations as shown in Figure 8. Two type of strain gauges were used, the first type for steel reinforcement (KFH-20-120-C1-11L1M2R 120 20) produced by Omega company and the second for concrete (PL-60-11) produced by TML company. Data logger type (TML/ TC-32K) was used to measure the strains in steel reinforcements and concrete. Four positions were selected to measure the strains, Figure 8. The first strain gauge was settled in main reinforcement at mid span, which is the maximum tensile stresses zone, which was designated by symbol (S-1). The second and third strain gauges were fixed perpendicular to the expected shear cracks direction, which may occur by approximately (45o), and they are represented by (S-2) and (S-

3), respectively. The last strain gauge was fixed at top flange near the mid span, in order to get an indication about the effect of variables on the maximum compressive stresses, which are at top fibres of beam; this strain gauge is designated by the symbol (S-4).

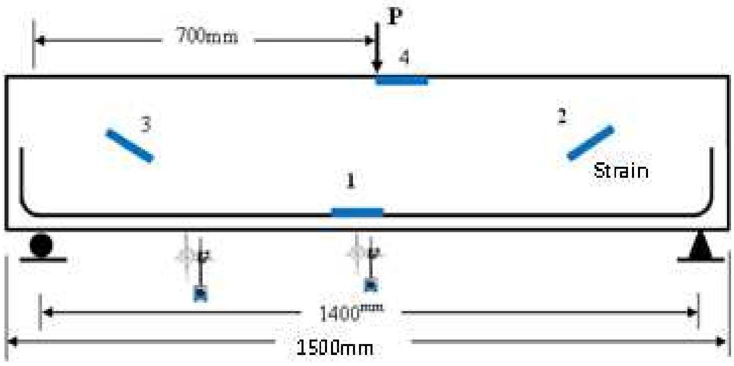

Figure 8: Strain and Dial Gauges Locations

Test Procedure

All beams and control specimens have been removed from water curing after 28 days. Before the testing day, the beams have been cleaned and painted with white colour paint for monitoring crack patterns and first crack easily. Each specimen has been labelled and the locations of support points, loading point and the dial gauges' positions were marked on the surface to facilitate the precise setup of the testing machine. The beams have been placed on the testing machine at free supported roller at each end, with an effective span of (1400mm). All beam specimens have been tested under monotonic one concentrated load at mid-span of the beam. The dial gauges were mounted in their marked positions to touch the bottom of the beam. All beam specimens were loaded up to failure. Each beam was initially exercised by applying a small load to ensure that the test setup and the instrument worked properly. The beams were loaded in increments of (5kN) for the beams without strengthening, whereas the specimens with strengthening were loaded in increments of (10kN). The positions and extents of the first and the other consequent cracks were marked on the surface of the beam, and the magnitude of the load stage at which, these cracks happened was marked. As failure occurred, when the beam failed abruptly at simultaneity, with the load indicator stopped in recording or return back and the deflection increased very fast. The failure load was recorded, and the load was removed to allow taking some photographs of the crack pattern and the mode of failure.

RESULTS AND DISCUSSIONS

During the experimental work, ultimate loads, load versus deflection and strains were recorded. Photographs for the tested beams are taken to show the crack pattern and some other details. The recorded data, general behaviour and test observations are reported as well as recognizing the effects of various parameters on the shear behaviour.

General Behaviour

Test results are given in Table 6 and Photographs of the tested beams are shown in Figures 9. The general behaviour of the tested beam specimens can be described as follow: At early stages of loading, all tested beams were in elastic state, where the defects in their structure and the cracks did not appear at any place and the deflections at mid-span were small and proportional to the applied load, consequently the stresses were small and the full cross section was

effective in carrying the loads. At about (25%) from the ultimate load, flexural cracks were observed first in the in the bottom of beam at maximum moment region (At mid of span). As the load increased, the first diagonal crack (web shear crack) appears at the mid height of the diagonal region bounded by load and support positions in both shear spans at the same load level or little different and then extended upwards toward the load point, then these inclined cracks multiplied and became wider in shear spans. One or more cracks propagated faster than the others and reached the top flange (near the applied load where crushing of the concrete near the positions of applied loads had occurred due to high concentrated stresses under the point load) and nearly horizontally at the level of the longitudinal reinforcement toward the support in the other direction. The top flange was cracked in longitudinal and transverse axes. The failure occurs by splitting the beam into two parts, approximately along the line joining the edge steel blocks at the support and point of loading, where the loaded part drop by some millimetres away from the other part. This mode of failure can be considered as a "Diagonal Tension Failure". In strengthened beams, the failure modes were CFRP debonding.

Table 6: Test Results of Beam Specimens

Group No	Beam Designation	Load (kN)		Pcr / Pu %	Vu (kN)	Mode of Failure
		P_{cr}	P_u			
1	B1G1*	42.5	133.5	31.8	66.75	Diagonal Tension Failure
	B2G1	49	149	32.9	74.5	Diagonal Tension Failure
	B3G1	65	267.5	24.3	133.75	Debonding
	B4G1	52	157.5	33.0	78.75	Diagonal Tension Failure
	B5G1	54	187	28.9	93.5	Diagonal Tension Failure
2	B1G2*	50	174	28.7	87	Diagonal Tension Failure
	B2G2	56.5	184	30.7	92	Diagonal Tension Failure
	B3G2	74	310	23.9	155	Debonding
	B4G2	62	189	32.8	94.5	Diagonal Tension Failure
	B5G2	66	203	32.5	101.5	Diagonal Tension Failure
3	B1G3*	59	206	28.6	103	Diagonal Tension Failure
	B2G3	85	360	23.6	180	Debonding
	B3G3	66.5	230	28.9	115	Diagonal Tension Failure
	B4G3	98	382	25.7	191	Debonding
	B5G3	88	240	36.7	120	Diagonal Tension Failure
	B6G3	102	405	25.2	202.5	Debonding
	B7G3	95	283.5	33.5	141.75	Diagonal Tension Failure
	B8G3	108	435	24.8	66.75	Debonding

*Reference Beam

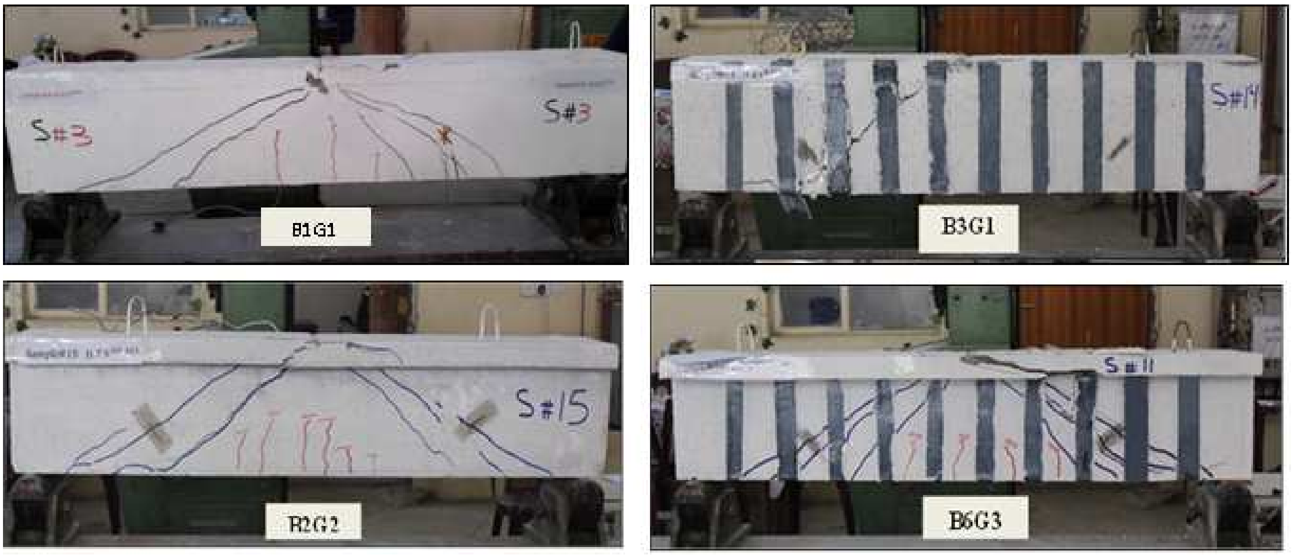

Figure 9: Crack Patterns for Tested Beams

ULTIMATE STRENGTH (Pu)

Ultimate loads of the tested beams are presented in Table 6. For the first group, the ultimate load increased about (11%, 18%) when the wall web thickness increased from (50mm) to (62.5mm) and (75mm) respectively, and it increased about (40%) when the beam was casted without hollow (solid section) in comparison with the reference beam. This gives indication that the increase in web thickness makes proportional increase in both shears strength and beams stiffness. This increase may be due to the increasing of concrete portion in the web, which increases the effectiveness of concrete to resist the shear forces. The ultimate capacity of beam (B1G3), which has (62.5mm) wall web thickness externally got strengthened by ten (50mm) width strips of CFRP, increased about (80%) in comparison with the same wall web thickness beam and about (100%) compared with the reference beam. For the second group, when the wall web thickness increased from (50mm) to (62.5mm, 75mm), the ultimate capacity increased about (6%, 9%) respectively, and increased about (18%) when the beam becomes solid. The ultimate capacity increased about (69%) when the tested beam which has (62.5mm wall web thickness) has been strengthened by CFRP strips compared with the same beam but without strengthening, and about (80%) compared with reference beam.

The increase in top flange width from 200mm (rectangular beam) to 300mm led to increase in the ultimate capacity about (30%, 24%, 20%, 10%) in comparison to its counterpart beams (wall web thickness wise) (50mm, 62.5mm, 75mm and solid) in the first group, respectively. It may be concluded that the shear strength of T-beams is much higher than the shear strength of the rectangular beams of their web. This is due to the increase of the compression zone (Flange), which is able to sustain larger compressive forces and increases the stiffness of the testing T-beams, and this leads to an increase in carrying capacity.

For the third group, whose beams have a Tee shape with (400mm) width of top flange, the beam (B1G3) which has maximum hollowness ratio (50mm wall web thickness) is considered as the reference beam for the other seven beams. The ultimate load capacity increase about (10%, 18%, 37%), when the wall thickness has been increased from (50mm) to (62.5mm, 75mm, and became a solid). Each beam of this group has a strengthened counterpart beam with same amount and distribution of CFRP, the presence of this strengthening increases the ultimate load capacity about (75%, 67%, 69% and 55%) for wall web thickness of (50mm, 62.5mm, 75mm and became a solid), respectively.

The ultimate load capacity increased about (18%, 25%, 27% and 19%), when the width of top flange increased from (300mm) to (400mm) in comparison to its counterpart beams (wall web thickness wise) (50mm, 62.5mm, 75mm and solid), and increased about (54%, 55%, 53% and 52%) when the top flange width increased from (200mm) (rectangular) to (400mm) for the same above arrangement. It is shown that increase in the top flange width of a T-beam gives higher shear capacity because, the area of concrete on the flange of a T-beam can provide an additional area for the compression zone, so the average stress at failure can be reduced and the shear capacity of the T-beam can be improved.

First Cracking Load (PCR)

The first cracking loads are reported and presented in Table 6, and the crack patterns for all tested beams are shown in photographs of Figure 9. The visible first diagonal crack loads of the tested beams varied from (24%) to (36%) of the experimental ultimate loads, and all the first diagonal crack were initiated at a position approximately mid-depth of the tested beams.

For the first group, the first cracking loads increase about (16%, 23%) when the wall web thickness increased from (50mm) to (62.5mm, 75mm) respectively, and it increased about (28%) when the beam was casted without hollow (solid section) in comparison with the reference beam. This gives indication that the increasing in web thickness makes proportional increase in the first cracking loads, and delays the initiation of cracks. The first cracking loads of beam specimen (B3G1), which has (62.5mm) wall web thickness and has external strengthening by ten (50mm) width strips of CFRP, increased about (34%) in comparison with the same wall web thickness beam and about (55%) compared with the reference beam.

For the second group; when the wall web thickness increased from (50mm) to (62.5mm, 75mm), the first cracking load increased about (14%, 24%) respectively, and increased about (32%) when the beam became solid. The first cracking loads increased about (31%) when the beam has (62.5mm) has been strengthened by CFRP strips compared with corresponding without strengthening beam, and about (48%) compared with reference beam.

The increase in top flange width from (200mm) (group-1) to (300mm) led to increase in the first cracking loads about (18%, 15%, 19%, 22%) in comparison to its counterpart beams (wall web thickness wise) (50mm, 62.5mm, 75mm and solid) in the first group, respectively.

For the last group; the first cracking load increase about (13%, 49%, 60%), when the wall thickness has been increased from (50mm) to (62.5mm, 75mm, and became solid). Each beam of this group has a strengthened counterpart beam with same amount and distribution of CFRP strips, the presence of this strengthening increases; the first cracking load increase about (44%, 47%, 16% and 14%) for wall web thickness of (50mm, 62.5mm, 75mm and solid) respectively.

The first cracking load increased about (18%, 18%, 41% and 66%), when the width of top flange increased from (300mm) to (400mm) in comparison to its counterpart beams (wall web thickness wise) (50mm, 62.5mm, 75mm and solid), and increased about (39%, 36%, 69% and 75%) when the top flange width increased from (200mm) (rectangular) to (400mm) for the same above arrangement. As mentioned before, when the top flange width of T-beam increases, the compression zone increased, and this lead to increase the ability to sustain larger compressive forces and increases the stiffness of tested T-beam, and as a result, this leads to increase in carrying capacity. As a result, the flange width appeared to be effective in delaying the formation of first cracks, or at least in arresting their initial growth.

Load –Deflection Curves

In general, the load-deflection relationships determined from loading tests of reinforced concrete beams, failing in flexure provide a general demonstration of the behaviour of these beams under the loads. However, these relationships cannot be used directly for same purpose in the case of shear failure, but can be considered as a useful means of comparing the behaviour of the present test beams under different conditions throughout the variations of the test variables. Load-deflection curves of each group at mid span and third of span at all stages of loading up to failure, are plotted and presented in Figures 10 to 15. Each curve initiated in a linear form (the beam is in elastic manner) with a constant slope, changed to a nonlinear form with varying slope. Then, the third stage starts when the deflection increases very fast, with small increase in the applied load.

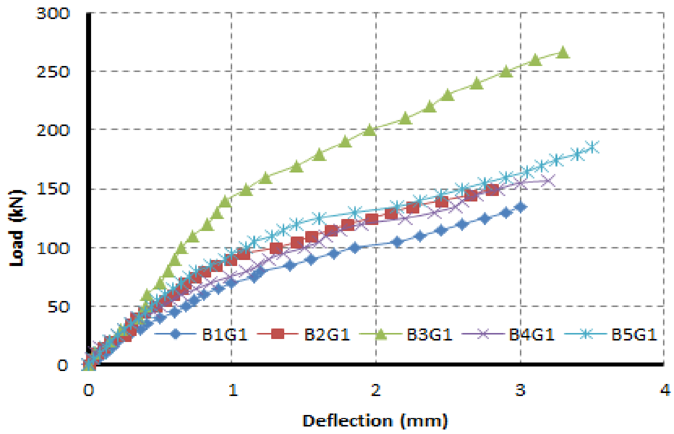

Figure 10: Load-Deflection Curves for Group-1 at Mid-Span

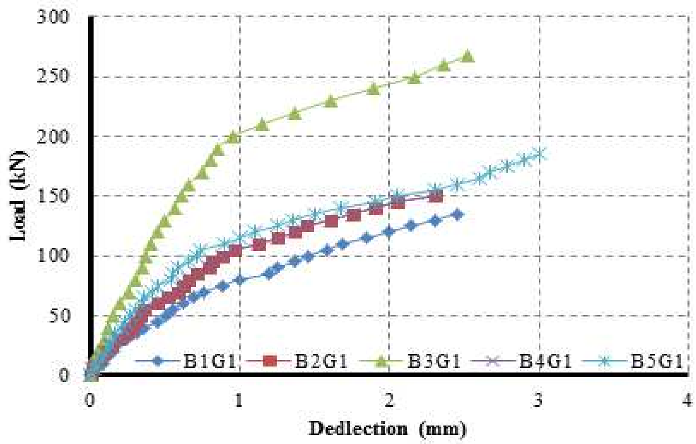

Figure 11: Load-Deflection Curves for Group-1 at (1/3) of Span Beams

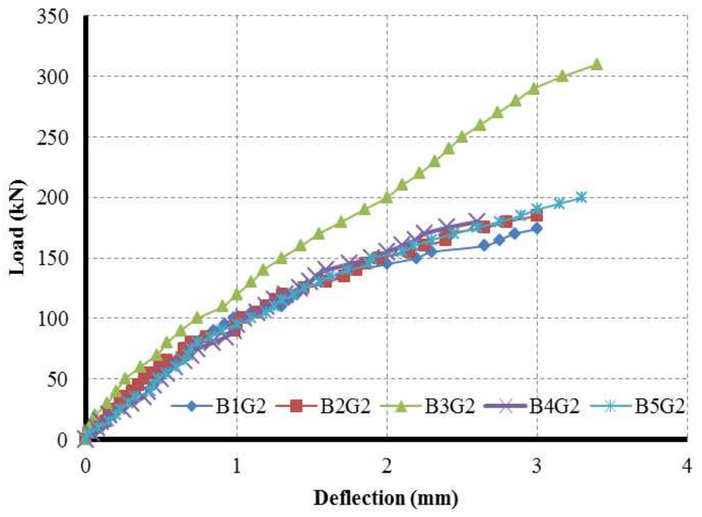

Figure 12: Load-Deflection Curves for Group-2 at Mid-Span

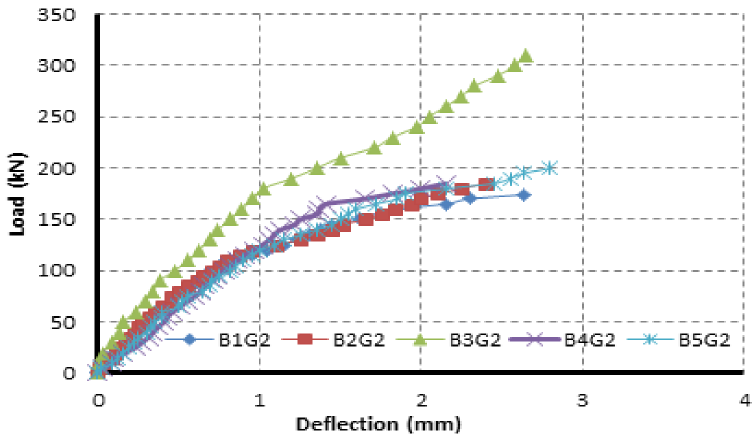

Figure 13: Load-Deflection Curves for Group-2 at (1/3) of Span Beams

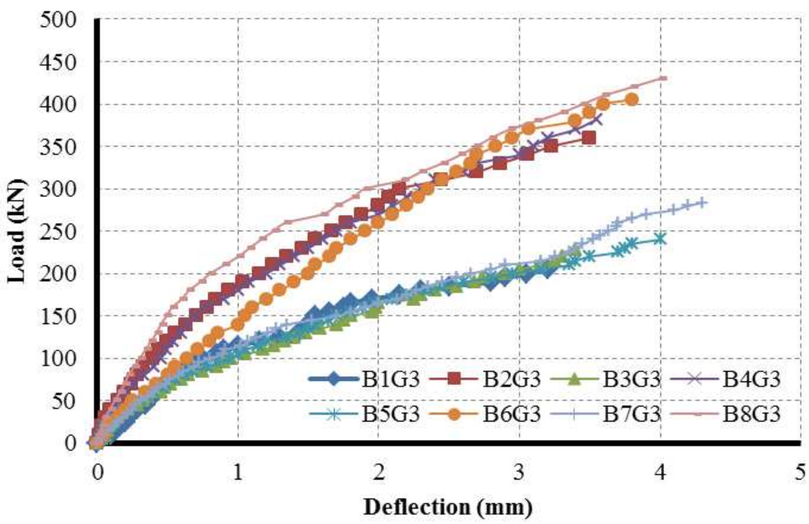

Figure 14: Load-Deflection Curves for Group-1 at Mid-Span

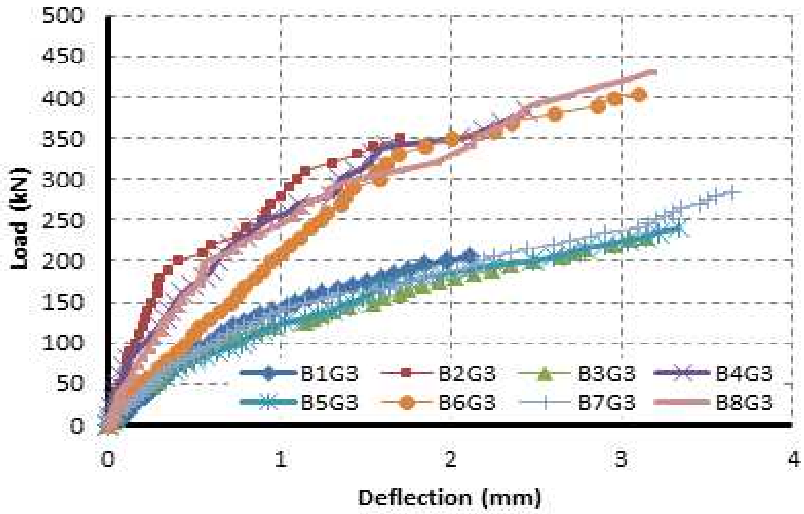

Figure 15: Load-Deflection Curves for Group-1 at (1/3) of Span Beams

As shown in Figures 10 to 15, the increase of wall web thickness exhibits an increasing in load carrying capacity, and this is reflected in the corresponding deflections, this is due to that the moment of inertia and stiffness of beams increase with the increasing of web thickness. It can be noted that at a certain load level, the beam which have lesser hollowness ratio has lower deflection values; this may be due to the influence of moment of inertia where it increased as the wall web thickness increase as well as the stiffness. The increasing in ultimate deflection and carrying load capacity of T-beams which have top flange width (300mm) compared with the rectangular beams and also for T-beams which have top flange width (400mm) compared with those beams which have (200mm) and (300mm) top flange width. This is may be due to that the increasing in top flange width of T-beam causes an increase in the stiffness and the load carrying capacity beyond the first cracking, and this is reflected in the corresponding deflections.

In each figure, it is noted that the beams which strengthened with CFRP strips continued in carrying load for about twice the loading capacity of beams without strengthening, and this is reflected in the corresponding deflections. The presence of CFRP strips increases load carrying capacity, as a result, the toughness (area under load deflection curve) of the beams gets increased, so the absorption of deformations was increased.

Load-Strain Behaviour

The instruments for strain monitoring were carefully engineered to provide the data and information, much needed for the understanding of the mechanisms of shear resistance involved in reinforced concrete beams. It must be realized that all the recorded data was subjected to careful examination, study, and comparisons. The load-strain relationships for beam specimens (groups) are shown in Figures 16 to 18.

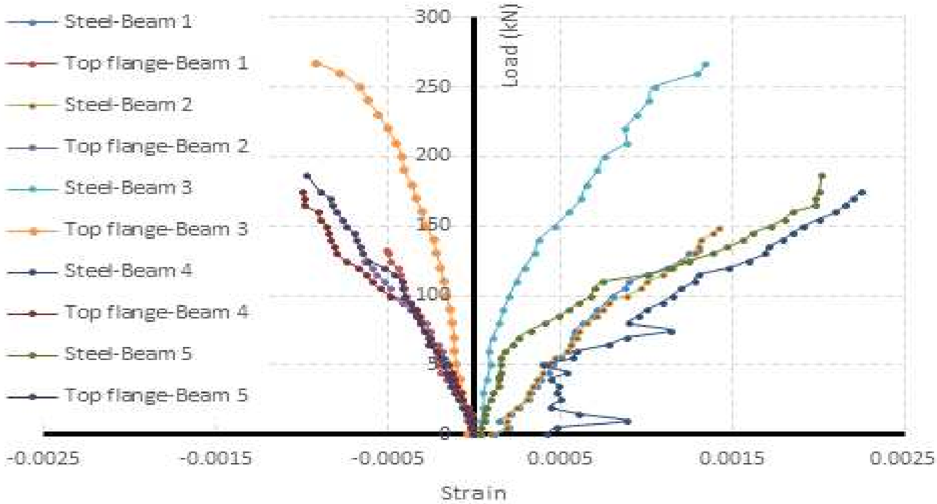

Figure 16: Load-Strain Relationship for Group-1

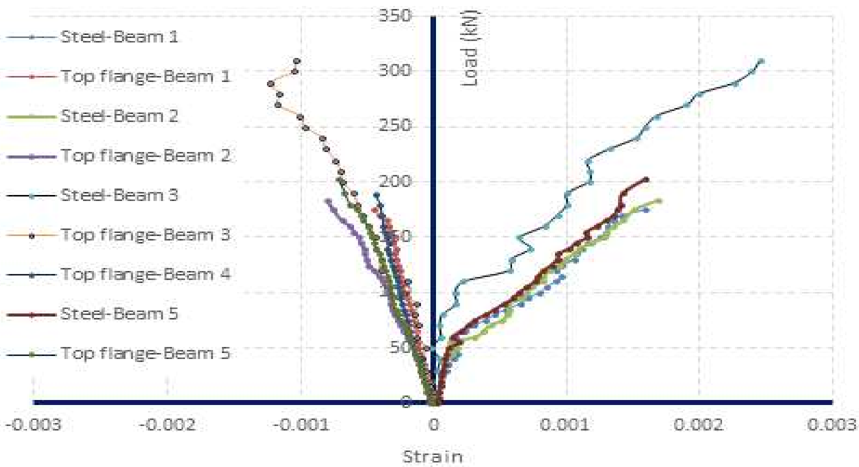

Figure 17: Load-Strain Relationship for Group-2

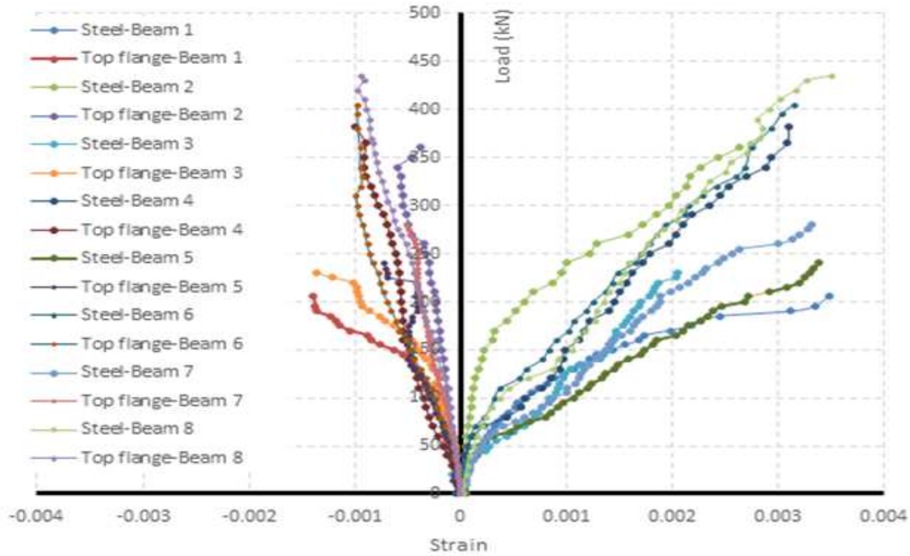

Figure 18: Load-Strain Relationship for Group-3

CONCLUSIONS

Based on the results obtained from the experimental work, the following conclusions are presented: -

- For rectangular beams, when the webs thickness increased from (50mm) to (62.5mm, 75mm and casted without hollow), the ultimate load capacity increased about (11%, 18% and 40%) respectively and the first crack load increased about (16%, 23% and 28%) respectively.
- For T-beams with (300mm) flange width, the ultimate capacity increased about (6%, 9% and 17%) respectively, when the webs thickness increased from (50mm) to (62.5mm, 75mm and casted without hollow) respectively, and the first crack load increased about (14%, 24% and 32%) respectively.
- For T-beams with (400mm) flange width, when the webs thickness increased from (50mm) to (62.5mm, 75mm and casted without hollow) the ultimate load capacity increased about (10%, 18% and 37%) respectively, and the first crack load increased about (13%, 49%, 60%) respectively.
- Increase in top flange width from 200mm (rectangular beam) to 300mm led to an increase in the ultimate capacity about (30%, 24%, 20% and 10%) in comparison to its counterpart beams (webs thickness wise) (50mm, 62.5mm, 75mm and solid) respectively, and increased the first crack load about (18%, 15%, 19%, 22%) respectively.
- Increasing of top flange width from 300mm to 400mm led to an increase in the ultimate capacity about (18%, 25%, 27% and 18%) in comparison to its counterpart beams (webs thickness wise) (50mm, 62.5mm, 75mm and solid) respectively, and increased the first crack load about (18%, 18%, 41% and 66%) respectively.
- Increase in top flange width from 200mm (rectangular beam) to 400mm led to an increase in the ultimate capacity about (54%, 55%, 53% and 52%) in comparison to its counterpart beams (webs thickness wise) (50mm, 62.5mm, 75mm and solid) respectively, and increased the first crack load about (39%, 36%, 69% and 75%) respectively.

REFERENCES

1. *Lars, J.R., "**Plastic Behaviour of Deformable Reinforced Concrete Box Sections under Eccentric Load**", Ph.D. Thesis,*

University of Queensland, (1996).

2. *Al-Janabi, W.A., "**Analysis and Shape Optimization of Varied Section Box Girder Bridges**", M.Sc. Thesis, University of Tikrit, (2005).*
3. *Taljsten, B., "**Strengthening Concrete beams for shear with CFRP Sheets**", Construction and Building Materials, vol. 17, pp. 15-26, (2003).*
4. *Neale, K. W., **"FRPs for Structural Rehabilitation: A Survey of Recent Progress"**, Progress in Structural Engineering and Materials, V. 2, pp. 133-138, (2000).*
5. *Chiad, S. S., "**Shear Stresses of Hollow Concrete Beams**", Journal of Applied Sciences Research, Vol. (9), No.(4),pp.(2880-2889). (2013).*
6. *Hassan, R. Y., **"Evaluation of Shear Strength of RC deep box beams strengthened internally by Transverse Internal Ribs",** MSc thesis, Al-Mustansiriyah University, (2015).*
7. *Aziz, A. H., **"Effect of Transverse Internal Ribs on Shear Strength Evaluation of Hollow RC Beams"**, Journal of Engineering, Vol. (22), No. (2), February (2016).*
8. *Aziz, A. H., A. A., Alfeehan ans Hussein, F. A., **"Strengthening of continuous SCC hollow beams under shear stresses using warped CFRP strips",** Civil and Environmental Research, Vol. (8), No. (3), (2016).*
9. *ACI Committee 318, "**Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary (ACI 318R-08)"**, American Concrete Institute, Farmington Hills, MI, 2008, pp.465.*
10. *ASTM C39-96, **"Test Method for Compressive Strength of Cylindrical Concrete Specimens",** (ASTM C39-96), American Society for Testing and Materials, (1996).*
11. *BS 1881-116, **"Method for determination of compressive strength of concrete cubes"**, British Standards Institute, London, (1983).*
12. *ASTM C496-96, "**Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens**", (ASTM C496-96), American Society for Testing and Material, (1996).*
13. *ASTM C 469-02, **"Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression",** (ASTM C 469-02), American Society for Testing and Material, (2002).*